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ENGINEERING EVALUATION OF THERMAL INSULATION OF  
MAGNESIUM-MANGANESE DIOXIDE DRY BATTERY PERFORMANCE

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April 1975

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Substantial improvements in magnesium-manganese dioxide ( $Mg/MnO_2$ ) dry battery performance were obtained by thermally insulating the battery to retain the heat evolved during discharge. The influence of discharge temperature at 130°F and 220°F on discharge capacity of individual cells is assessed relative to 74°F capacity between the 25 and 100 hour discharge rate. Magnesium Batteries BA-4386/PRC-25 ( $A_2$ Section), surrounded by varying thicknesses of thermal insulation, were discharged at a constant 5 Watt drain at operating temperatures varying from minus 25 to plus 160°F. Sizable		

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improvements (greater than three times) in performance were obtained at minus 25°F and plus 20°F.

Performance data are presented for Magnesium Battery BA-4840/U, with and without insulation, and with and without a nickel-cadmium (NiCd) battery in a hybrid configuration. Over six times the capacity was obtained at 40°F with a hybrid battery system versus no hybrid. At 20°F the hybrid system capacity was improved over six times by the addition of insulation around the BA-4840/U.

The available capacity from a BA-4386/PRC-25 (A<sub>2</sub> section) Battery in hybrid with nine 250 mAh NiCd cells on a 1 minute and 9 minute duty cycle with a 100 ms pulse with loads of 4.7/40/1.75 ohms with and without insulation is presented.

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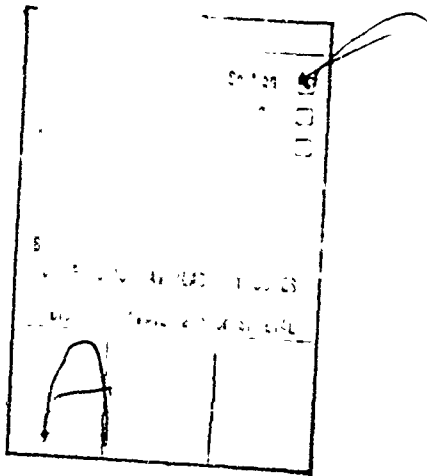
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# ENGINEERING EVALUATION OF THERMAL INSULATION ON MAGNESIUM MANGANESE DIOXIDE DRY BATTERY PERFORMANCE

## INTRODUCTION

Substantial improvements in magnesium manganese dioxide ( $\text{Mg/MnO}_2$ ) dry battery performance were obtained by thermally insulating the battery to retain the heat evolved during discharge. According to Krebs and Ryan,<sup>1</sup> this heat is evolved from two sources at the magnesium anode - that generated because of the difference between the operating and theoretical voltages, and that produced by the parasitic corrosion reaction.

Magnesium in an aqueous solution operates about 1.1 V below its theoretical voltage. This voltage differential causes heat energy to be evolved as the magnesium anode discharges. The amount of heat energy evolved is related directly to the current drawn from the cell and can be expressed as follows:

$$Q = 1.1 (I)T \quad (1)$$

where Q is expressed in watthours, 1.1 is an approximation of the Volts below theoretical at which the anode functions, I is the current drain in amperes, and T is the time in hours. (To express the heat energy in calories, the watthours are multiplied by 860.)

In the parasitic corrosion reaction the magnesium anode reacts with the water in accordance with the following reaction:

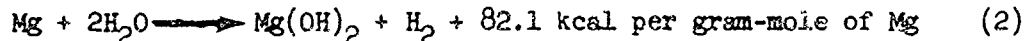


Figure 1 shows an approximation of the combined effect of the two sources of heat at various anode efficiencies versus the current of a single cell.<sup>1</sup> The efficiency appropriate for communication equipment type drains is 75%.

## EXPERIMENTAL PROCEDURES

The use of thermal insulation surrounding the  $\text{Mg/MnO}_2$  dry battery was investigated as a means of retaining the heat generated by the battery during discharge and thus improving its performance by raising the operating temperature. Various size magnesium dry batteries were evaluated under

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<sup>1</sup>  
T. K. Krebs and R. Ryan, "High Capacity Magnesium Batteries," Final Report, Contract DA36-039-SC-85340 (ECOM), Radio Corporation of America, November 1962.

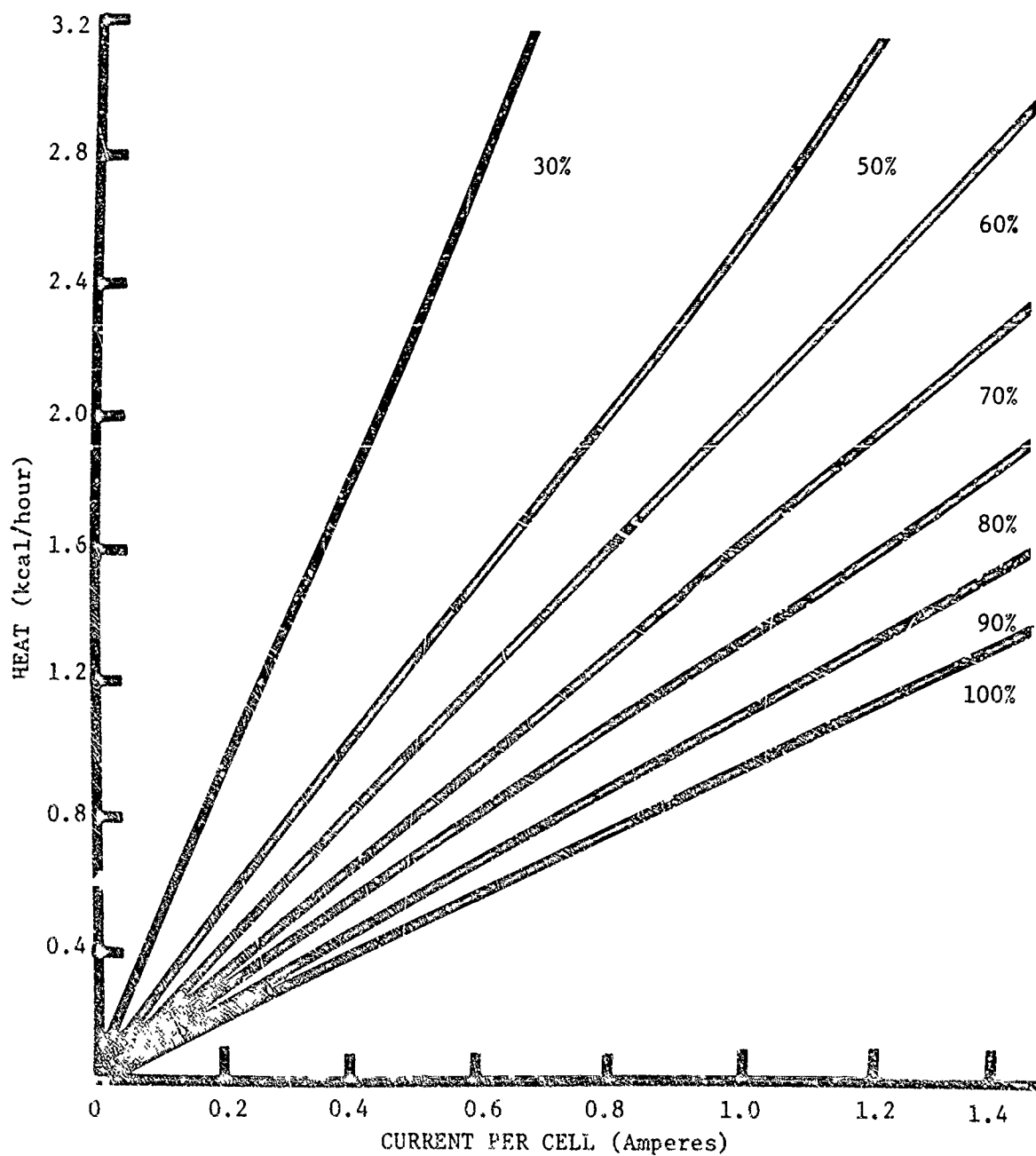


Figure 1. Heat Evolved From Magnesium Anode

several conditions with different thicknesses of thermal insulation. In some cases, nickel-cadmium (NiCd) batteries were used in parallel with the Mg/MnO<sub>2</sub> dry battery in a hybrid configuration. Since thermal insulation could cause the batteries to reach high operating temperatures, individual Mg/MnO<sub>2</sub> dry cells were discharged at 130 and 220°F in order to determine the influence of these temperatures on cell performance.

### Insulation, Batteries, and Equipment

Rigid polyurethane, density 2.0 pounds per cubic foot, was used as thermal insulation. On one test, 3/8 inch thick insulation was encased in steel walls, 0.065 inches thick. On the other tests the insulation was not encased in steel, and varying thicknesses, including 3/8 inch, were evaluated to establish the influence of thickness on capacity. On all tests the void between the surface of the battery and the inner surface of the insulation was less than 1/4 inch.

Three different batteries were utilized in this investigation. The "CD" size Mg/MnO<sub>2</sub> dry cell (0.935 inches in diameter x 3.3 inches high) was tested individually. Magnesium Battery BA-4386/PRC-25, manufactured by high speed production equipment, was used in the "as received" condition. This battery measures 3.625 inches x 2.125 inches x 9.50 inches and weighs 2.60 pounds; the 14.4 Volt A<sub>2</sub> section contains about 3.6 ampere-hours capacity at the 20 hour discharge rate. A 3 Volt A<sub>1</sub> section is included in the battery but was not used. Magnesium Battery BA-4840/U was constructed with sixty-four cells, each one measuring 0.939 inches in diameter by 3.18 inches in height. The cells were connected in series-parallel to provide two nominal 14.4 Volt sections. Each section contained thirty-two cells, eight cells in series, four stacks in parallel. This battery weighs 9.8 pounds and has the following dimensions: length 11.61 inches, width 3.42 inches, and height 6.00 inches. The nickel-cadmium batteries used were of the sealed cylindrical type with a capacity of 250 mAh. Two 250 mAh cells in parallel were employed to make a 500 mAh capacity battery.

Battery operating temperatures were determined by placing a thermocouple against the midpoint of the largest side (based on area) of the battery.

All tests, other than those in the 70°F range, were conducted in a Tenney Mite 5 temperature cabinet manufactured by Tenney Engineering, Inc. The 70°F and 74°F tests were conducted in air-conditioned rooms. Unless noted otherwise, all batteries were pre-soaked at least sixteen hours prior to discharge at the indicated ambient temperature.

### Discharge Programs

#### Individual Cells at High Temperatures

High temperature can be produced within an insulated battery compartment by the heat generated during discharge of the Mg/MnO<sub>2</sub> dry battery. In order to establish the influence of high temperatures on the discharge capacity of the Mg/MnO<sub>2</sub> dry cell, groups of five each individual production line "CD"

cells were subjected to various discharge loads at 74°F, 130°F, and 220°F as follows: 7.5 ohms (20-hour discharge rate) continuously, 30.0 ohms (100-hour discharge rate) continuously, and 2.5 ohms/50.0 ohms on a 2 minute/18 minute duty cycle repeated continuously. The 2-minute periods of the latter test represent a heavy drain rate (6-hour discharge rate). The discharges were conducted to a cutoff of 1.25 Volts.

BA-4386/PRC-25 at Constant 5 Watt Drain

The A<sub>2</sub> section of Battery BA-4386/PRC-25 was subjected to a constant 5-Watt discharge to an end voltage of 10 Volts at various temperatures and with insulation as indicated, in accordance with the following schedule:

Thickness of Insulation In Inches	Discharge Temperature			
	<u>-25°F</u>	<u>20°F</u>	<u>40°F</u>	<u>160°F</u>
None		X	X	
1/8	X	X		
1/4	X	X		X
3/8	X	X		X
1/2	X	X	X	

X - Indicates Test Run.

---

No metal box surrounded the insulation. The voltage during discharge was observed closely and appropriate changes made in the resistance so that the wattage was maintained as closely as possible to 5 Watts.

Battery BA-4840/U Under Various Load Conditions

Two discharge programs were used to evaluate Battery BA-4840/U against the operational requirements of a field radio transceiver now in development. The discharges were on a 1 minute/9 minute duty cycle, repeated continuously.

Both sections of the BA-4840/U were discharged concurrently to an end voltage of 10 Volts. The evaluation was carried out in accordance with the following program:

Loads for each 14.4 Volt Battery Section	Discharge Temperature					
	No Hybrid		Hybrid			
	70°F	40°F	70°F	40°F	20°F (Not Insulated)	20°F (Insulated)*
1.5 ohms/65 ohms	X	X	X	X	X	X
2.5 ohms/100 ohms	X	X	X	X		

\* - 3/8 inch thick insulation, encased in steel walls, surrounded the battery.

X - Indicates Test Run.

The hybrid configuration consisted of eighteen 250 mAh NiCd cells (connected in series-parallel) in parallel with each 14.4 Volt section of Battery BA-4840/U. Charge control circuitry was not used. The NiCd battery was not encased in the insulation.

#### High Current Drain For BA-4386/PRC-25 - NiCd Hybrid

The A<sub>2</sub> section of Battery BA-4386/PRC-25, in parallel with a nine-cell 250 mAh NiCd battery, was discharged thru 4.7 ohms/40 ohms, to an end voltage of 10 Volts, on a 1 minute/9 minute duty cycle, repeated continuously. Each 1 minute interval was preceded by a 100 ms pulse thru 1.75 ohms. The evaluation of the hybrid battery was made in accordance with the following schedule:

Ambient Temperature °F	Hybrid Battery System <sup>a</sup>	Hybrid Battery System <sup>b</sup>	Hybrid Battery System with Insulated BA-4386/PRC-25 Encased in a Metal Box <sup>a</sup>
20	X	X	X
40	X		X
70	X		

a - Soaked at indicated temperature at least 16 hours prior to discharge.

b - Soaked at indicated temperature for no more than 1/2 hour prior to discharge.

X - Indicates Test Run.

This evaluation was selected to show that current delivering limits of the hybrid system can be reached and what influences these limits have on operating capacity.

## DISCUSSION AND RESULTS

### Individual Cells at High Temperatures

Table 1 shows the service in hours and the capacity in ampere-hours obtained from individual "CD" size Mg/MnO<sub>2</sub> dry cells at temperatures of 220°F, 130°F, and 74°F. The capacities are influenced by the interactions between discharge temperature and the length of time on discharge.

Table 1. Average Service For Individual "CD" Size Cells

Discharge Temperature °F	Loads In Ohms					
	7.5*		30.0*		2.5/50**	
	Hrs	Ah	Hrs	Ah	Hrs	Ah
220	21.5	4.82	58.0	3.64	36.2	3.51
130	28.0	6.05	89.2	5.09	50.0	4.56
74	19.5	3.68	102.0	5.44	59.0	5.17

\* - Discharged continuously.

\*\* - Discharged on a 2 minute/18 minute duty cycle,  
repeated continuously.

Voltage versus time discharge curves are shown in Figure 2 for the 7.5 ohm discharge. As expected, a higher ambient temperature resulted in an elevation of the operating voltage. This was also true for the 30 ohm and the 2.5 ohm/50 ohm discharges.

The increased voltage does not account entirely for the decrease in service observed. At 220°F, a lower ampere-hour capacity was obtained on each test when compared to the 130°F results. This behavior can be attributed to moisture loss. After the 30 ohm continuous discharge and the 2.5/50 ohm, 2 and 18 minute discharge, the cells all exhibited small holes, or pitting, on the anode. This pitting occurred during discharge because the chromate inhibition system did not protect the entire anode's surface. (Any non-uniform corrosion early in the cell's discharge could initiate this process by providing a site of corrosion into which the chromate ion might not penetrate.) The rate of the resulting corrosion increased as the operating temperature rose and the corrosion process consumed vital cell moisture. In addition, the holes also provided a path for moisture to escape from the cell and, at the same time, these holes provided a path for air depolarization.

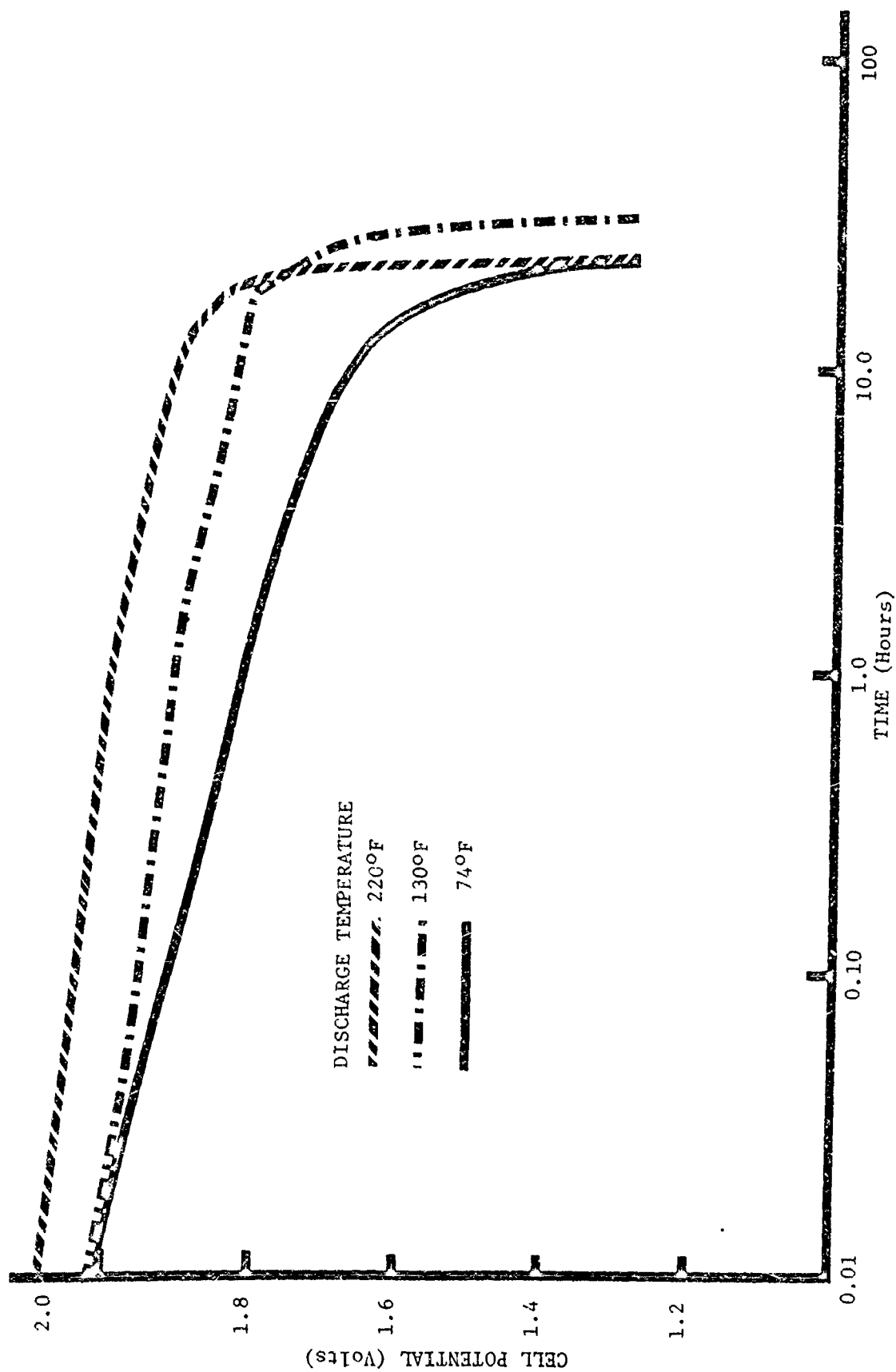


Figure 2. Voltage Vs Time Curves For "CD" Size Mg/MnO<sub>2</sub> Cells Discharged Through 7.5 Ohms

#### BA-4386/PRC-25 at Constant 5 Watt Drain

Capacity obtained with various thicknesses of insulation around Battery BA-4386/PRC-25 while subjecting the 14.4 Volt section to a constant 5 Watt discharge at various ambient temperatures is shown in Table 2.

The use of insulation had a marked influence on battery capacity. At an ambient temperature of 20°F, battery capacity increased threefold when 1/8 inch thick insulation was employed as compared to no insulation. At an ambient temperature of -25°F little or no capacity would be obtained with no insulation, but at least 7.7 hours of useful service were obtained with 3/8 inch thick or more insulation. The difference in battery performance with 3/8 inch thick insulation between the 16 hour soak period and the 1/2 hour soak period may be due to variation in the batteries. The voltage delay data at -25°F is presented to indicate that at low temperatures the delay time can be very substantial if the battery is cold-soaked for a lengthy period before discharge. Starting with a warm battery curtailed the lengthy delay time. At 20°F, no delay was observed but surely some small delay (less than a minute) did occur and was not sensed on the device used to measure the voltage because of its slow operating speed.

In addition to the data presented in Table 2, at 40°F, an average of 12.6 hours of service was obtained with no insulation and 17 hours (to an end voltage of 12.6 Volts) with 1/2 inch insulation. At 160°F, 27 hours were obtained with 1/4 inch insulation and 25.5 hours with 3/8 inch insulation; the battery surface temperature reached 177°F and 183°F, respectively. Since these battery temperatures did not have a severe negative influence on battery capacity, it is assumed that the individual cell temperature did not reach a level high enough to adversely affect performance.

#### Battery BA-4840/U Under Various Load Conditions

The advantages gained by hybridizing Battery BA-4840/U with the NiCd battery and also insulating the BA-4840/U against heat loss are shown in Table 3. The results given represent the average of two tests in each case.

The results in Table 3 show that a hybrid configuration must be employed to obtain any significant performance at 40°F. At 20°F, the insulated hybrid configuration is required to get more than just the few hours obtained with the hybrid configuration alone. No delayed action was exhibited by the hybrid design in either case. The NiCd battery portion (1 pound, 27 cubic inches) of the system represents an increase in weight of 10.2% and an increase in volume of 11.5%, with both percentages based on the weight (9.8 pounds) and volume (235 cubic inches) of the Mg/MnO<sub>2</sub> battery.

#### High Current Drain for BA-4386/PRC-25 - NiCd Hybrid Configuration

The hybrid combination of the 14.4 Volt section of Battery BA-4386/PRC-25 and a nine cell 250 mAh NiCd battery is service limited as the current drain increases or the temperature falls. The use of insulation to raise the battery's operating temperature cannot always overcome the deleterious influence of the combination of high current and low temperature.

Table 2. 5 Watt Discharge of Battery BA-4386/PRC-25 With Various Thicknesses of Insulation

Thickness of Insulation (Inches)	Performance at -25°F			Performance at +20°F	
	Service (Hours)	Voltage Delay* (Minutes)	Maximum Battery Surface Temperature Observed	Service (Hours)	Maximum Battery Surface Temperature Observed
None				5	
1/8	4.3	72	0°F	15	50°F
1/4	4.5	20	0°F	15-17	60°F
3/8	7.7** 9	<1** 60	10°F	17 to 11.7 end voltage	65°F
1/2	14.2** 11.4	<1** 15	45°F	17-19 to 11.0 end voltage	90°F

\* - Delay time not included in service

\*\* - Battery soaked 1/2 hour at indicated temperature before discharge.  
All other batteries soaked 16 hours before discharge.

Table 3. Service in Hours of 14.4 Volt Section of Battery BA-4840/U

<u>Loads (Ohms):</u>		<u>1.5/65*</u>	<u>2.5/100*</u>
<u>Battery Configuration</u>	<u>Discharge Temperature °F</u>	<u>Service</u>	<u>Service</u>
No Hybrid	70	15.9	27.8
	40	2.0 estimated	4.3
Hybrid - Not Insulated	70	18.4	30.0
	40	14.5	24.2
	20	2.2	-
Hybrid - Insulated**	20	17.8	-

\* - Discharged on a 1 minute/9 minute duty cycle, repeated continuously.

\*\* - 3/8 inch rigid polyurethane, 2 pound/cubic foot density, encased in 0.10 inch steel walls.

Table 4 presents the data obtained when the hybrid combination was discharged on a 1 minute/9 minute duty cycle, repeated continuously, thru 4.7 ohms/40.0 ohms, respectively. In this sequence, each 1 minute period was preceded by a 100 ms pulse load of 1.75 ohms. The beneficial influence of insulation at 40°F is shown. A threefold increase in capacity was realized when compared to the performance without insulation. At 20°F the use of insulation did not help when the battery was cold soaked and allowed to reach the ambient temperature before the discharge was started. Zero service indicates that the operating limit of the battery system was exceeded at the operating temperature for the current drain encountered. At lower current drains, the limit would occur at lower temperatures.

The lack of service is attributed to the inability of the Mg/MnO<sub>2</sub> battery to provide the voltage required to recharge the NiCd battery at +20°F when the hybrid battery system is subjected to a 40.0 ohm load.

Table 4. Service For Hybrid Consisting of Battery BA-4386/PRC-25 and Nine 250 mAh NiCd Cells

<u>Ambient Temperature °F</u>	<u>Point at Which Voltage Reading was taken</u>	<u>Hours of Service<sup>a</sup></u>	<u>Hours of Service<sup>b</sup></u>	<u>Hours of Service<sup>c</sup></u>
20	Pulse	0	2.0	0
	1 Minute	0	2.3	0
40	Pulse	3.4	-	12.3
	1 Minute	3.6	-	12.3
70	Pulse	15.3	-	-
	1 Minute	15.5	-	-

- a - Hybrid soaked at least 16 hours before discharge.
- b - Hybrid soaked no more than 1/2 hour before discharge.
- c - Battery BA-4386/PRC-25 was encased in 3/8 inch thick insulation. The NiCd portion was not included within the insulation. This combination soaked at least 16 hours before discharge.

## CONCLUSIONS

Heat evolved by the  $\text{Mg/MnO}_2$  dry battery during discharge can markedly improve battery performance, especially at low temperatures, if thermal insulation is employed to retain the heat within the battery compartment. The more insulation (up to 1/2 inch thick), the more capacity is obtained at low ambient temperatures; however, at high ambient temperatures, the reverse can be true at low discharge rates.

For communication type operation, the benefit obtained by employing insulation around the  $\text{Mg/MnO}_2$  battery can be further improved by hybridizing it with a nickel-cadmium battery. However, in the design of battery using equipment, overall operating temperatures and discharge rates should be considered. In hybrid designs there are limits in the performance improvements; the limits are dependent on the ability of the  $\text{Mg/MnO}_2$  battery to recharge the NiCd battery. This ability depends on the operating temperature and the magnitude of the low current load.